2+1-Roads With and Without Cable Barriers: Speed Performance

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ABSTRACT

The objective of this paper is to present the SNRA development program to upgrade traffic safety on existing 13 m using low cost measures and early findings on speed performance. Traffic safety findings have been reported in depth elsewhere.

The main traffic safety proposal in the development program is conversion to 2+1 with a separating cable barrier and roadside improvements within existing right-of-way. In 1998, the director general of SNRA decided to proceed with a full-scale program with six sections. The empirical findings presented here are based on 1.5 years of experience from the first section to be opened; the E4 semi-motorway Gävle-Axmartavlan with an AADT of 7000 veh/d; 2+1 partly with cable barrier partly only with road markings.

The solution chosen on the first section give one-lane sections with a total paved width of 5.6 m but only 4.6 at existing bridges and side guardrails. This has been heavily criticized as giving an unacceptable level-of-service for a national highway due to low overtaking opportunities and queues at vehicle breakdowns and maintenance operations.

Early speed performance findings so far could be summarized:

- the average car spot speed at speed limit 90 km/h has been 101 km/h. The change of speed limit to 110 km/h increased the actual average speed to 107 km/h.
- car spot speeds are in the range 93–100 km/h at the beginning of a one-lane section at traffic flows around 1200–1350 veh/h.
- 5% of the hourly speeds are below 90 km/h at speed limit 90 km/h.
- the 1% percentile speed at 90 km/h is 75 km/h at both the beginning of a one-lane and at the end of the two-lane location close to a transition zone.
- car spot speeds on overtaking lanes, 300–350 veh/d, are very high, in the range 110–120 km/h, far above the official speed limit of 90 km/h (before April 1999).
- average passenger car spot speeds on two-lane sections are 4 km/h higher in September 1998 on the cable barrier section compared with September 1997 with wide lanes. On two-lane sections with road marking the spot speeds are slightly higher than for the cable barrier section.
- passenger car speeds on one-lane sections on the cable barrier part are more or less unchanged though speeds at side steel barriers have decreased some km/h. Speeds on the road marking part seem to be approximately 2 km/h higher in one-lane sections. Side cable barriers 1 m from the pavement do not affect speeds.
- approximately one median barrier repair per week requiring on average a 2 hour overtaking lane closure.

- two illegal transports, one with a over-width truck and one with a over-height truck, have been stuck resulting in long queues.
- some five accidents and incidents have blocked one direction for numerous hours.

1. OBJECTIVES

The objectives of this paper are to

- describe the present 13 m road network in Sweden
- give an overview of the SNRA development program to upgrade traffic safety on existing 13 m two-lane roads with 2+1-conversion with median cable barrier as the main tool
- summarize the preceding debate whether the anticipated negative effects on speed performance due to the narrow one-lane sections should be accepted on national roads
- report on early findings on speed performance issues based on 1.5 years of experience from the first 2+1 cable barrier road E4 Gävle-Axmartavlan

2. EXISTING 13 m TWO-LANE ROADS IN SWEDEN

There is a huge gap in traffic performance, safety, investment and maintenance costs, land requirement and intrusion between two-lane and four-lane cross-sections. In Sweden, this gap has so far been filled with a 13 m cross-section with two traffic lanes, 3.75 m each, and two hard shoulders, 2.75 m each, with dotted road markings.

Alternative 13 m cross-sections were introduced in the 1990s with the objective to improve safety; with 5.5 m lanes and 1.0 m hard shoulders separated with embossed edge markings and with road marking based 2+1:designs, i.e., with a middle lane changing direction every 1–2.5 km, see Figure 1.

The national road network, approximately 10000 km, include some 3600 km 13 m roads with AADTs varying from 4000 to 20000 veh/d. Speed limits are mostly 90 or 110 km/h. Only some 300 km are semi-motorways, i.e., grade separated with full access control, no pedestrians, bikers and slow-mowing traffic. The present guidelines give 13 m roads as an opportunity in the traffic interval AADT opening year from 2000 to 12000 veh/d.

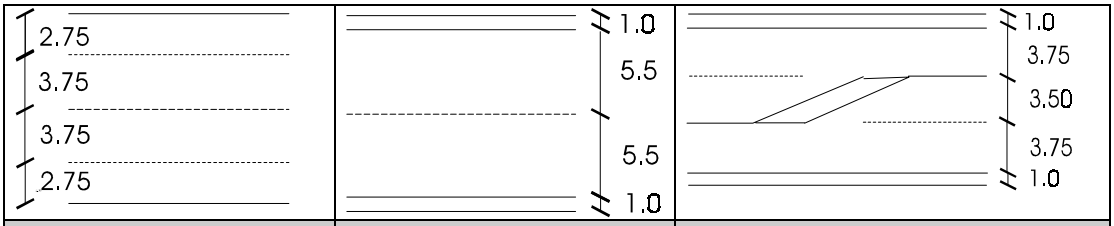


FIGURE 1 Swedish intermediate cross-sections.

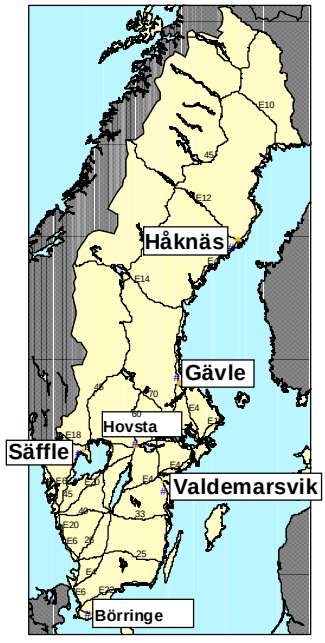
2.1 Safety Experiences

The 13 m roads are judged to be some 10% better than normal two-lane 9 m roads. Wide lanes have turned out not to be a traffic safety success so far (Brüde and Larsson 1996). The very limited Swedish experiences of 2+1-designs with road markings (Brüde and Larsson 1997) have not been by far as promising as the German findings (Brannolte et al. 1993).

Almost 100 people die and about 400 people are severely injured every year on 13 m roads due to the huge traffic load. This comprises 25% of all fatalities and 20% of all severely injured on national roads (Bergh 1999a). The main problems, more than 50% of all casualties, on all two-lane roads including 13 m roads are run-off and head-on or meeting accidents. The event process tends to be the same. The driver looses control of his vehicle due to some reason and crashes against some obstacle in the roadside area or in the shape of an opposing unlucky driver. Safety problems seem to be related to lack of concentration, fatigue and monotonous driver perceptions on roads with high standard and low event frequencies.

3. DEVELOPMENT PROGRAM FOR EXISTING 13 m ROADS

In 1998, the director general of SNRA decided on a full-scale program to improve traffic safety on existing 13 m roads using low-cost measures preferably within existing right-of-way (Figure 2).



Road	Object	Measure	AADT	Constr. years[2)]	Km [1)]	Million SEK[1)]
E65	Börringe-Skurup	15,75:2+2 cb	9500	00-01	10	100
Rv60	Hovsta-Lilla Mon	15,75:2+2cb	10000	00-01	20	124
E4	Håknäs-Stöcksjö	13:2+1cb	5300	00-01	33	90
E4	Gävle-Axmartavlan	13:2+1cb	7000	98-00	33	32
Rv45	Åmål-Säffle	13:2+1cb	6000	00	19	34
E22	Valdemarsv.-Söderköping	13:2+1cb	5500	01-02	35	60

1) Name, planned opening year, length and investment cost according to the NSRA proposal on National investment scheme for 1998-2007

2) Forecasts December 1999

FIGURE 2 Alternative 13 m development projects.

The main alternative is the 2+1-solution with a separating cable barrier preferably within the existing width 13 m denoted 13: 2+1cb. A second more costly alternative is to widen up to a narrow 4-lane road; 15.75:2+2cb, primarily in order to improve speed performance and decrease safety risks at vehicle breakdowns and to ease maintenance tasks.

The objectives are to find suitable design procedures, detailed designs and maintenance specifications for these measures and also to validate the positive safety effect estimates, expected to be in the range from 20 to 50% reduction of severe accidents for 2+1. The program includes intensive follow-up studies of traffic safety, behavior and attitudes as well as construction and maintenance costs and problems.

The general analysis project combined with a number of feasibility studies proposes that the 2+1-alternative could be realized within a budget of 2 Million SEK/km (1 Euro = 8.6 SEK) and the 2+2 within 6 Million SEK/km excluding maintenance costs. The final design stage tend to give costs for 2+1 around 2 Million SEK/km for semi-motorways and 3–5 Million SEK/km if not semi-motorway due to high regional requests.

4. LEVEL OF SERVICE CRITICS

The SNRA decision to start the development program was preceded by a very intense debate whether the anticipated negative effects on speed performance due to the narrow one-lane sections were acceptable on national roads. Some voices also worried about traffic safety especially at transitions and for motor bikes. The proposed 13:2+1-cb give a one-lane section total paved width of 5.1 m and lengths without overtaking opportunities varying from 1 to 2.5 km. 1+1-sections are recommended to avoid limited lateral width at critical passages, e.g. existing bridges (Figure 3).

The main critical views could be pinpointed as follows:

- deteriorated overtaking opportunities resulting in lower average speeds and according to some also major capacity reductions
- long queues due to road blockages at truck failures

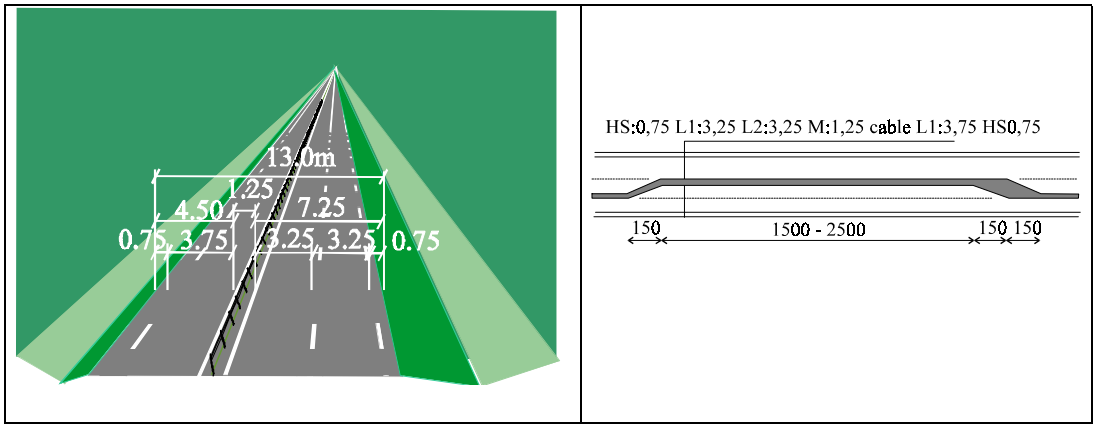


FIGURE 3 Proposed standard 2+1-cable barrier cross-section within existing 13 m.

- hindrance for over-width and over-weight transports restricted to bridge center line passes
- slower emergency transports and also problems to reach the accident spot
- slow speeds and blockages at snow ploughing, surface repairs, etc.

5. E4 GÄVLE-AXMARTAVLAN

E4 Gävle-Axmartavlan was the first road with 2+1-cable barrier development to be opened. This took place in June 1998 for the southern 14 km. The remaining 18 km had been redesigned to 2+1 with road markings in September 1998. The cable barrier was extended to 23 km in September 1999 and will be completed to the full 32 km in spring 2000.

The 32 km road section was originally opened in 1987 as a 13 m semi-motorway with an AADT of 7000 veh/d. Wide lanes were introduced in 1991. The road has a smooth alignment without straight elements in a very flat landscape with only one interchange. Driving is claimed to be very monotonous. The speed limit was decreased from 110 to 90 km/h in November 1996 and increased to 110 again in April 1999 after the redesigning to 2+1 road.

Twenty-one people were killed from 1987 to 1997, 15 of them in meeting or head-on accidents and 4 in single run-offs. Fifty-nine were severely injured, 29 of these in meeting and 22 in single run-off accidents. The in-depth analysis of the severe accidents proposes that the now implemented measures should have avoided some 70% of the fatal and severe injuries.

5.1 Design

The E4 Gävle-Axmartavlan has been redesigned as follows:

- There were at the start ten 2+1-sections with cable barrier and twelve with road marking. The lengths of the sections (excluding transition zones) vary from 0.9 to 1.8 km. The length depends on alignment, locations of interchanges, etc. 1+1-designs were considered but not used at existing side guardrails. There was no need for 2+2-sections to avoid 1-lane sections on up-hills and to improve traffic.
- Transition zones from 2 to 1 lanes have a length of 150 m, totally 300 m for both directions. The transition zone has delineators on the cable poles at a distance of 10 m with double-sided lane closure information signs 400 m ahead and at the start of the transition zone (Figure 4). Quick-locks make it possible to open the cable barrier in each transition. Transition zones from 1 to 2 lanes are 100 m.
- The cross-section within the existing 13 m comprises of (Figure 5):
  - 1.50 m median with a continuous cable barrier in CEN containment class N2 and working width W5
  - 3.50 m wide traffic lanes and 0.5 m outer hard shoulders
  - an added escape strip of 1.0 m with full bearing capacity on one-lane sections and transition zones

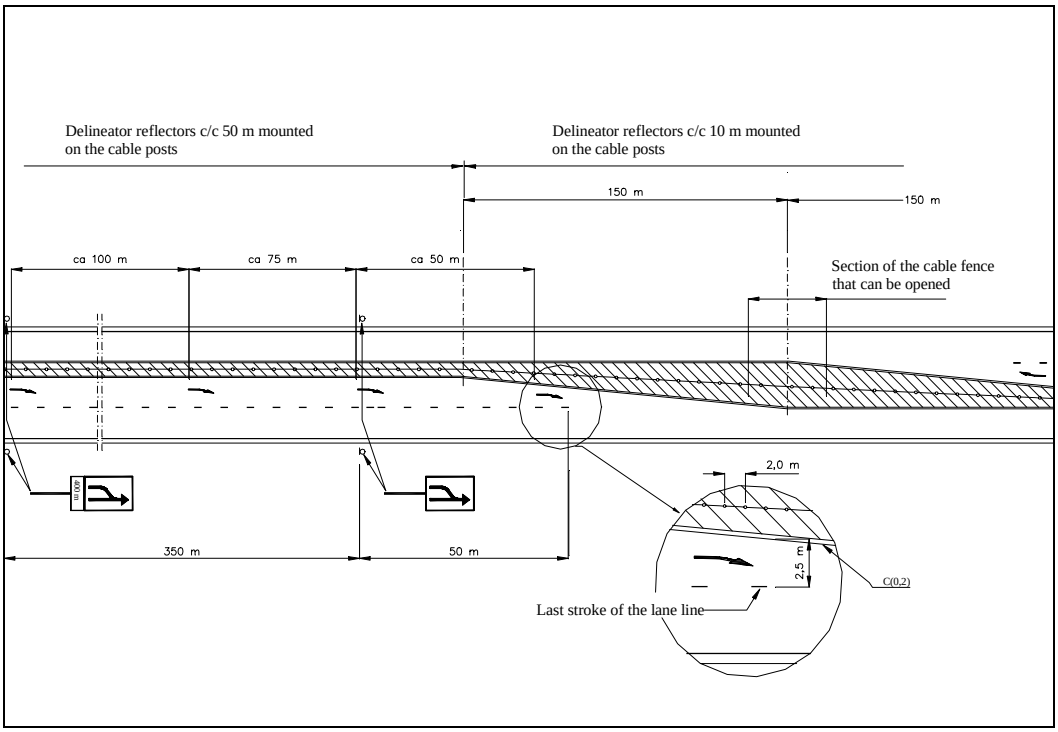


FIGURE 4 Design principles for 2 to 1 lane transition zone.

The lateral width on the one-lane sections is then normally 5.6 m but only 4.6 m along locations with existing side guardrails. The emergency strip was originally graveled not to invite ordinary traffic. It was paved in September 1999.

- The one-lane roadside areas have been designed with a full 1:6 layout including the transition zones. In the two-lane-section roadside areas only existing poles, trees, etc. have been taken away. In the second stage, side cable barriers have partly replaced the smooth slopes (Figure 6).

FIGURE 5 E4 Gävle-Axmartavlan 2+1-design with cable barrier.

FIGURE 6 Example of side cable fence in a forest area.

- The maintenance standard includes the following requirements:
  - bridge inspections, overlay repairs, etc., should be coordinated to minimize the number of traffic diversions. Delineator post washing, etc., should be performed during low traffic volume conditions
  - snow should be removed in the first 0.4 m of the median. Edge lines should be visible.
- Permanent emergency openings have been established every 3–5 km in the cable barrier to allow rescue vehicles to turn.
- Cable barrier ends used are tested and approved. They don't cause any ramp effects.

5. SPEED-PERFORMANCE FINDINGS SO FAR

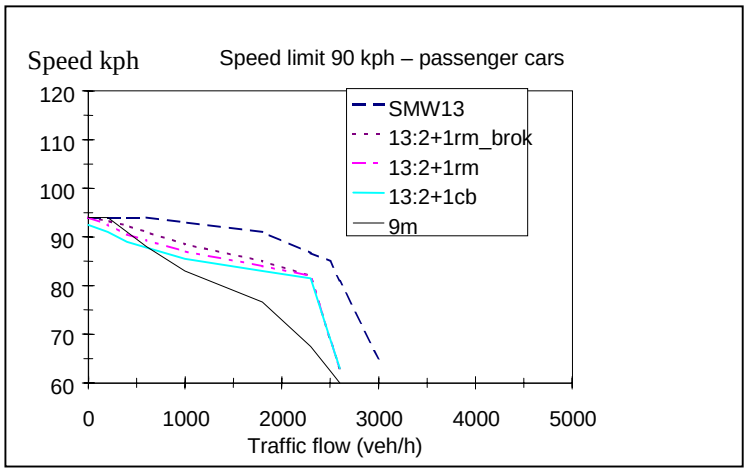
Level-of-service effects have been investigated by means of:

- a number of before and after spot speed measurements compared with a control section on an adjacent 13 m road, one before and one after measurement during 24 hours each in September. Furthermore there have been yearly measurements during one day from 1996, but in different spots during June every year.
- continuos lane based spot speed measurements on a location for southbound at the start of a one lane section and for northbound at the end of a two lane section.
- time studies on snow ploughing
- reports from emergency vehicles on vehicle breakdowns.

All speed measurements have been carried out with SNRA and VTI twin detector based standard equipment used for more than 20 years in Sweden.

5.1 Average Speed-Flow Effects

The feasibility study predicted passenger free flow car speeds to decrease a few km/h with a rather big flow impact based on experiences on 2+1 road marking designs and simulations (Figure 7):



SMW=semi motorway (no at-grade intersections, full access control)

brok=broken centerline, otherwise solid for 13:2+1 rm

FIGURE 7 Speed prediction (average two directions) at 90 km/h in feasibility study.

The simulations were based on the following assumptions:

- individual desired speeds are constant both on 13 m roads and in one-lane and two-lane sections on a 2+1 road
- all desired overtakings are performed in two-lane sections
- constrained vehicles always try to overtake and overtake by a first in first out rule
- the section length varied between 1 and 2 km
- capacities were estimated to 3,000 veh/h (two directions) for a two-lane road and 1,300 veh/h (one direction) for a 2+1 cable barrier road

The simulations indicated a rather large traffic flow impact on journey times on 2+1-roads, significantly higher than for a 13 m road. The simulations also supported the German recommendations that short one- and two-lane segments are to be preferred especially at high traffic volumes.

The main conclusions so far from measurements for average flow conditions, 200–300 veh/h and direction, are:

- Passenger car spot speeds on overtaking lanes, 300–350 veh/day, are very high, in the range 110–120 km/h, far above the official speed limit of 90 km/h (before April 1999).
- Average passenger car spot speeds on two-lane sections are 4 km/h higher in September 1998 on the cable barrier section compared with September 1997 with wide lanes. On two-lane sections with road marking the spot speeds are slightly higher than for the cable barrier section.
- Passenger car speeds on one-lane sections on the cable barrier part are more or less unchanged though speeds at side steel barriers have decreased some km/h. Speeds on the road marking part seem to be approximately 2 km/h higher in one-lane sections.
- Side cable barriers 1 m from the pavement do not affect speeds.
- The average car spot speed at speed limit 90 km/h has been 101 km/h. The change of speed limit to 110 km/h increased the actual average speed to 107 km/h.

Daily average journey speeds have increased about 2 km/h and speeds for trucks and buses 2–3 km/h.

Maximum traffic flows in the range 1200–1350 v/h with average speeds 93–100 km/h have been measured at the start of a one-lane section at speed limit 90 km/h (Figure 8). The flow impact seems to be very low, partly due to the measure point location. The horizontal line reflects the average speed for the total time period. The maximum hourly flows correspond to 30–35% of the AADT for this direction. Capacity is propably in the range 16–1700 veh/d.

6.2 Speed Time Variations Due to Flow, Time, Maintenance, and Incidents

Speed variations due to traffic flow, time of year, week, day, weather, maintenance operations and vehicle breakdowns are analyzed in Figure 9, illustrating maintenance operations (P = ploughing, SA = salting, SN = snowing), average and minimum hourly car spot speed and total traffic volume southbound per day at a location at the start of a one-lane section for week 34 to 53 1998. Cumulative hourly car speed distributions by direction and before/after the speed limit change from 90 to 110 km/h are shown in Figure 10.

Some interesting observations:

- Traffic volumes are extremely high on Sundays in August and September compared with an AADT of 3700 veh/d in this direction.
- No minimum hourly speeds below the speed limit before November 1998.
- Some 50% of December 1998 days have minimum hourly speeds below the speed limit.
- All minimum speeds below 80 in 1998 are due to snowfall, salting, or ploughing.
- There are no data indicating a speed effect due to vehicle breakdowns in 1998.

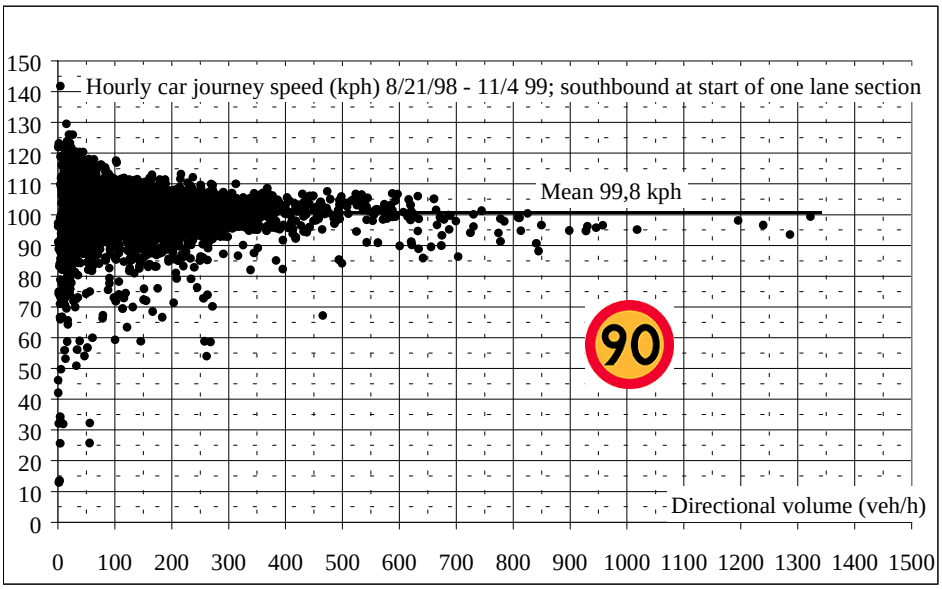


FIGURE 8 Hourly car speeds versus total flow (veh/h) at the start of a one-lane section.

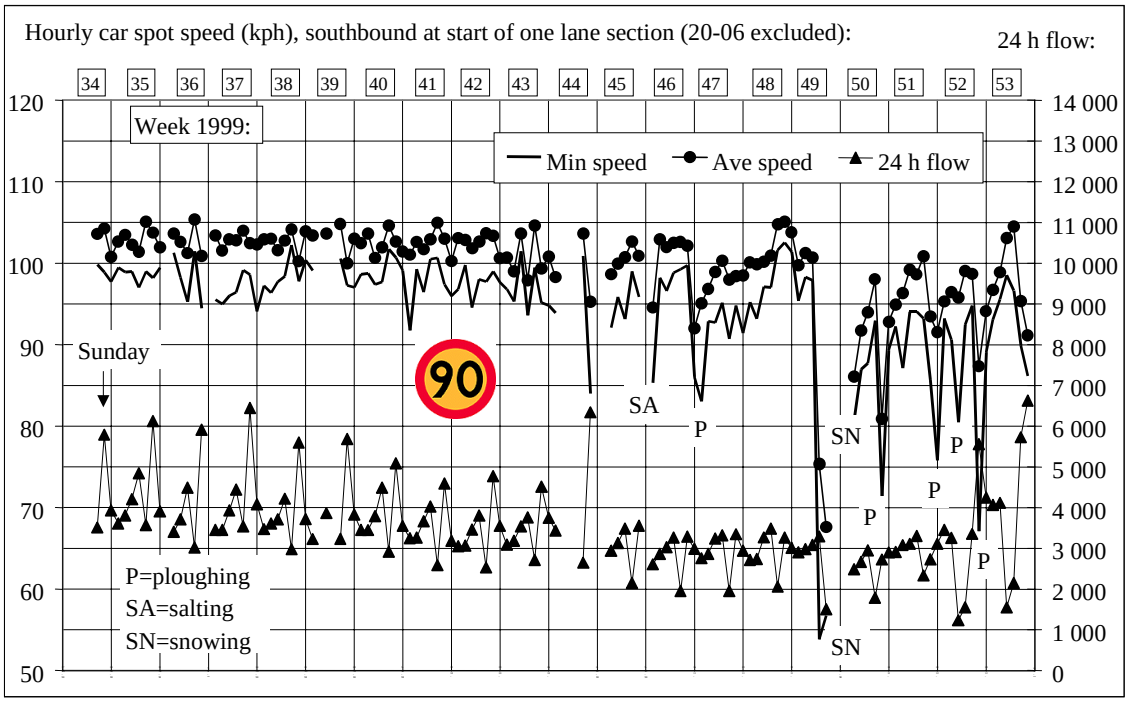


FIGURE 9 Speed variations due to traffic flow, time of year, week, day, weather, maintenance operations and vehicle.

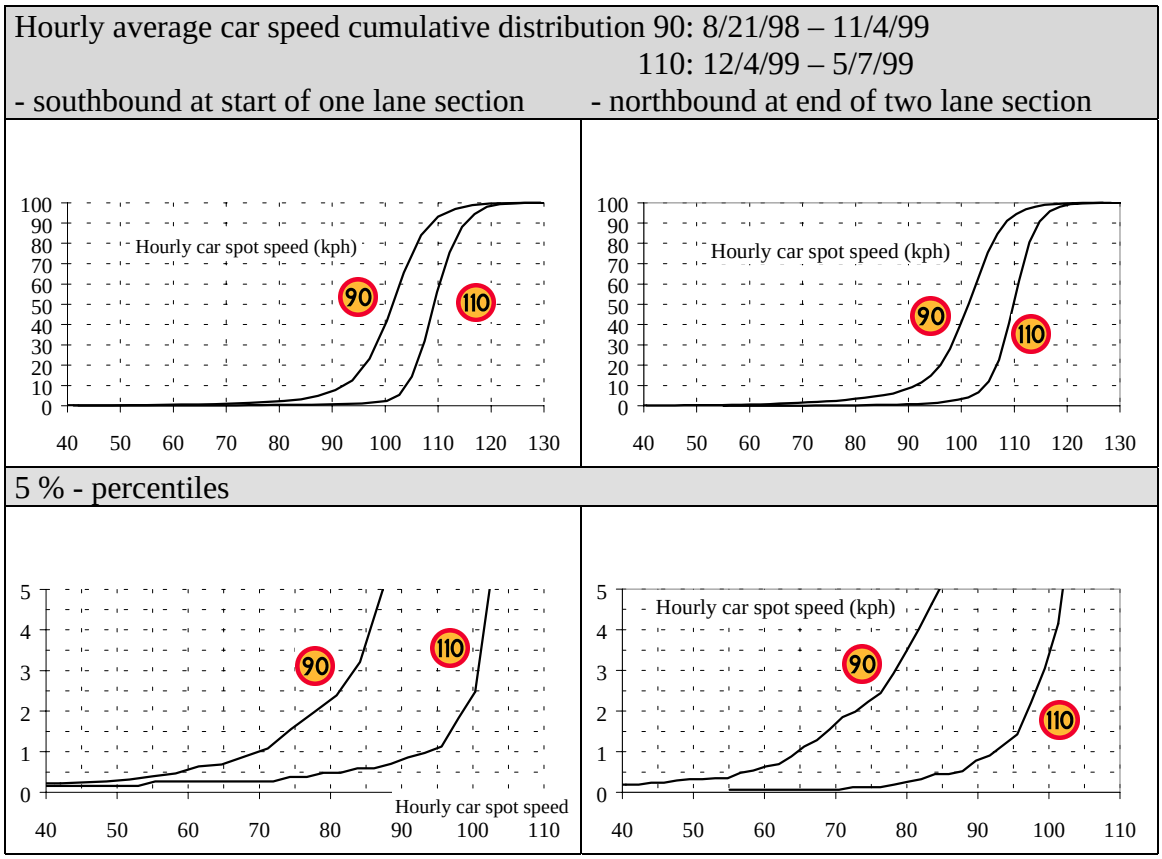


FIGURE 10 Cumulative hourly car speed distributions by direction and before/after the speed limit change from 90 to 110 km/h.

- About 5% of the hourly speeds are below 90 km/h for both directions at speed limit 90 km/h. At speed limit 110 km/h, 73% of the hourly speeds are below 110 km/h in southbound direction and 58% in northbound.
- The 1% percentile at 90 km/h speed limit is 75 km/h at both the one-lane and the two-lane location.
- At 110 km/h speed limit the 1% percentile is 100 km/h at the one-lane location and 102 km/h for the two lane.

6.3 Reported Incidents

The following incidents have been reported, which have affected speed performance:
- approximately one median barrier repair per week requiring on average a 2 hour overtaking lane closure
- two illegal transports, one with a over-width truck and one with a over-height truck, have been stuck resulting in long queues
- some five accidents and incidents have blocked one direction for numerous hours, one of these a vehicle breakdown

The rescue crew has only opened the cable barrier once so far.

6.4 Snow Ploughing

Time studies from snow ploughing before and after the redesign to 2+1 with a cable barrier and on a control section show that the snow ploughing speed is unaffected. Snow plough drivers complain that the task is more stressing than normal ploughing. The reasons are car drivers trying to overtake and the knowledge that the cable barrier collapses when hit by the plough. Overall, snow ploughing has created fewer problems than expected. Costs for snow removal has not increased.

7. EARLY CONCLUSIONS ON LEVEL OF SERVICE

The experiences from E4 Gävle-Axmartavlan indicate so far:
- 2+1-cable barrier designs at speed limit 90 km/h provide average service over the speed limit for one-lane traffic flows up to 1300 veh/h.
- Very few hours with low speeds, less than 1% with speed below 75 km/h, normally at snowfalls and ploughing.
- Very few vehicle breakdowns, so far only one reported, create problems with traffic queues.

There have been no accidents with fatal or severe injured persons. This means no complete stops and closed road for rescue work at severe accidents. Earlier the road was closed in both directions for many accidents (21 fatal accidents during 10 years). The number of stops has probably been reduced. But the level-of-service is slightly decreased in the two-lane sections at cable repairing, about two hours each week in some sections.

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